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Modelling of Fiber-Optic Radiation Sensor based on the Cerenkov Principle using Monte Carlo Simulation

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1. Introduction

Radiation sensors are widely used technique in detecting gamma rays in various fields such as medical and nuclear industries, it was used in the research such as radiation dose measurement or gamma flux monitoring [1,2]. Usually, radiation sensor using a scintillator attached at the one-ended surface of the optical fiber has been used for the sensor [3]. Recently, many studies on the Cerenkov effect in the optical fiber without scintillator materials have been conducted to measure response characteristics against gamma-ray [4,5]. The Cerenkov effect is a phenomenon that occurs when a charged particle travels through the medium with faster than the phase velocity of light in transparent medium such as an optical fiber [6].

Radiation detection experiments have many constraints for handling or use the radioactive source. When we are inaccessible to the radioactive source or we want to detailed configuration the interaction in the field test for the radiation detection, using the Monte Carlo-based computer program can be implemented radiation detection experiment.

The goal of this study is to develop the Monte Carlo-based GEANT4 codes for to simulate the Fiber-Optic Radiation Sensor based on Cerenkov principle and to examine the response characteristics of the sensor.

2. Methods and Results

The Monte Carlo-based GEANT4 (ver.10.02) code is based on a series of C++ classes, it is possible to configure a given step of the simulation like the geometry, particle and physics processes definition, particle tracking, hit definition and handling [7].

In this study, GEANT4 is used to simulate the all detection process, including the geometry, configuration of radioactive source, propagation of the Cerenkov effect in the optical fiber, and the Cerenkov photons finally collected in the cathode of the photomultiplier tube (PMT).

2.1 Reaction Modelling

Radioactive decay is used in the Decay process, we need input data such as the atomic number, location and shape of radioactive decay. The radioactive source emits its decay products. Among them, the gamma ray interaction with materials according to range of energy - photoelectric, Compton scattering, pair production.

In this simulation, the reaction model has configured the following procedures: the radioactive source is emit gamma ray by radioactive decay and it is generated an electron by Compton scattering. Then the electron in the optical fiber is traveling through faster than the phase velocity of light, it produce the Cerenkov effect.

Secondly, we have to consider a reaction in boundary of optical fiber. Thus, we used the Optical process and needs input data such as refractive indices, absorption length. These input data was refer to the specification of actual optical fiber model. The Optical process include boundary processes such as reflection, refraction, absorption.

2.2 Geometry Modelling

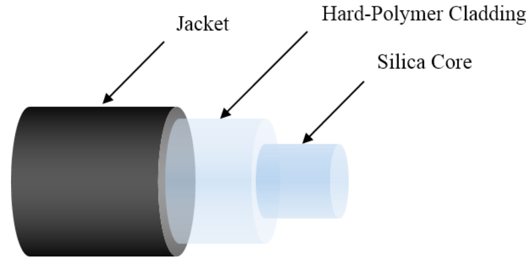

Fig 1. Structure of silica optical fiber (BFH48-1000).

Silica optical fiber used in this simulation are multimode optical fibers (BHF48-1000, Thor Lab). As shown in the figure 1, the core and cladding materials of these fibers consist of pure silica and hard-polymer. The core sizes of silica optical fiber are 1mm and the numerical aperture for these fibers is 0.48 [4,5].

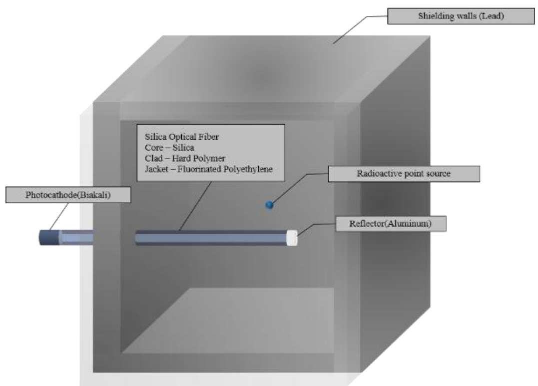

Fig 2. Schematic figures of the simulation.

A schematic of the simulation is shown in Figure 2. The experimental space is shielded with a box form of lead housing, 0.5m in thickness. The radioactive source have a point shape. Fiber-Optic Radiation Sensor is placed in 0.1m from the radioactive source, 10m in length. The Fiber-Optic Radiation Sensor is coupled to a reflector on the right (inside space) and a photocathode in photomultiplier tube on the left (outside space).

2.3 Simulation

In this simulation, we are used to simulate the sensor in three types of radioactive source and the characteristics of radioactive source are shown in Table1. We are simulated 1.E+06 times each. The range of wavelength is 200nm~700nm.

Table Ⅰ. Radioisotopes characteristics

Radioisotope	Half-life	Average gamma-ray energies (MeV)
^{60}Co	5.26yr	1.17, 1.33
^{137}Cs	30.3yr	0.662
^{192}Ir	74.2day	0.38

When the simulation is started, the radioactive source is emit gamma ray and it is enter into the optical fiber by reflection or collision. A Compton electron generated by Compton scattering, while traveling along the optical fiber generates the Cerenkov effect on account of second-order reaction. Finally, the moment optical photon hit the photocathode, record the kinetic energy of the Cerenkov photon. To convert recorded Cerenkov photon's kinetic energy to wavelength data, it is calculated using the following equation.

$$\lambda = \frac{h \cdot c}{E_{photon}} \quad (1)$$

h is the Planck constant, and c is the velocity of light. E_{photon} is the Cerenkov photon's energy and was recorded by simulation. We calculated the wavelength of Cerenkov photon for each of the radioactive source.

The results are presented in Figure 3. The maximum number of the Cerenkov photons appears at the Cobalt-60 radioactive source. Therefore, the number of Cerenkov photon increased proportional as increasing the gamma ray energy by emitted from radioactive source.

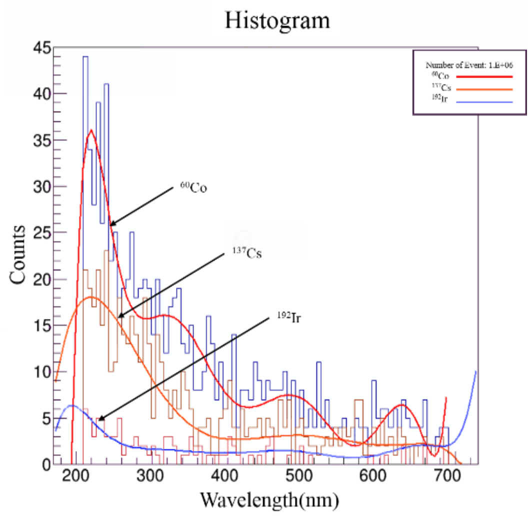

Fig 3. Calculated Cerenkov photon's energy according to radioactive sources.

3. Conclusions

In the radiation environments, the radiation sensor composed of the scintillator and the optical fiber is mainly used to detect radiation. Recently, radiation sensor is using the Cerenkov effect observed in optical fiber without any scintillator. The Cerenkov effect is produced directly by the interaction with Compton electron and optical fiber. In this study, we have developed the Monte Carlo-based GEANT4 codes in order to simulate the Fiber-optic Radiation Sensor based on Cerenkov principle and examined the response characteristics of the sensor. The simulation results are a good agreement with experimental results.

Further studies will be carried out to simulate a photon of Does distribution according to positions. It is expected that the program can be applied to develop the Fiber-Optic Radiation Sensor based on Cerenkov principle for various application fields.

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